BELLCOMM, INC.

SUBJECT: Effect of Landing Site Selection on LEM Descent Strategy Logic Case 320

DATE: April 26, 1966

FROM: R. E. Driscoll

SUMMARY

The details of the LEM powered descent strategy vary with the characteristics of the region selected for landing. This memorandum explores the qualitative tradeoffs in the descent strategy for the "possible" types of landing regions in order to identify the influence of site characteristics on the descent strategy.

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MEMORANDUM FOR FILE

I. Introduction

The details of the LEM powered descent strategy vary with the characteristics of the region selected for landing. This memorandum explores the qualitative tradeoffs in the descent strategy for the "possible" types of landing regions in order to identify the influence of site characteristics on the descent strategy. The possible types of landing regions are classified in terms of local distinguishable features or the lack of them and the relative goodness of the landing region.

II. Definitions and Assumptions

A landing region is defined as an area which contains the landing site and the terrain beneath the LEM approach corridor. A landing site is defined as an area whose size is at least as large as the expected 3σ LEM navigation error ellipse. A landing point is a smaller area contained within a landing site and is verified as suitable for a LEM landing. It is assumed that any given landing site contains several acceptable landing points. The LEM approach corridor is defined as the envelope of LEM approach paths possible, due to the LEM guidance and navigation uncertainties, beginning at the start of the powered descent and terminating at the touchdown point. It is assumed that the approach corridor is examined to determine the terrain over which the LEM must fly and that the terrain does not unduly constrain the descent profile.

A man-made marker is for the most part undefined. However, it is assumed that when a man-made marker is available the nominal landing point is "near" it and the distance at which the marker may be acquired is known or estimated in advance of the mission. Usable natural features are defined as objects which are distinguishable from other objects, located within the landing region and whose displacement from the landing point(s) is known a priori. It is assumed that these features are acquirable from a greater distance than the man-made marker. An "all good" site is defined as an area which contains no large protuberance and although there are

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craters to be avoided, their size and distribution are such that they can be avoided in the landing phase (Phase III) of the powered descent. That is to say that the corrective capability of the LEM in Phase III is sufficient to avoid these areas and land at an acceptable landing point.

Higate is defined as the transition from the braking phase to the visibility or final approach phase of the powered descent. At higate the LEM is pitched to an attitude which allows visual observation of the landing site. Logate is the transition from the final approach phase to the landing phase. At logate the LEM is pitched to a nearly vertical attitude, affording the crew a much improved view of the landing area.

III. Landing to a Site Containing a Man-made Marker

Figure 1 illustrates the four cases which are possible when the nominal landing point is selected near a man-made marker. The following discussion is an interpretation of Figure 1 for each of the four cases.

A. Case 1

The first type of landing region considered is one which has a man-made marker on the lunar surface, lunar orbiter photographs of the landing site and a pre-mission determination that the landing site is all good and the lunar terrain is homogeneous hence affords no clue as to the location of the marker. Alternate landing points, within the landing site, are selected with respect to the marker in the event the marker is acquired but cannot be reached. Landing to this type of region influences the descent strategy in the following manner.

Higate can be based on the estimated marker acquisition distance, corrected, if necessary, for the expected guidance and navigation uncertainties, including any bias. Should the initial landing point be biased, it would be biased uprange of the estimated marker position. Although this entails a ΔV penalty, it improves the probability of attaining the marker since the downrange corrective capability of the LEM is much greater than the uprange capability for the proposed quadratic guidance scheme. Therefore, if the marker is not acquired after a predetermined interval, the crew initiates a downrange correction and searches for the marker. If the marker is not acquired within a given interval, the process is repeated until the marker is acquired or until it is determined that the next correction would exceed the 3σ error ellipse bounds. Since the landing

site is determined to be all good, the entire visibility phase can be used, if necessary, to acquire the marker. After acquiring the marker the crew must insure that 1) the corrective maneuver required to reach the marker is within the allocated ΔV budget, and 2) line-of-sight to the marker is available for a sufficient interval prior to the vertical descent to the landing point for final landing point inspection.

If the marker is not acquired before logate, the crew selects an alternate landing point. If the marker is acquired but violates either of the constraints mentioned above, the marker is used to select a preplanned alternate point. In the alternate point selection process, the crew may decide to improve the visibility conditions by maneuvering the LEM through an azimuth turn. This maneuver assures improved visibility of surface relief during the landing phase. This maneuver can also be performed when landing to the nominal point. However, as the LEM rises above the sun line in the landing phase, the visibility should be sufficient for final landing point inspection without this maneuver since the landing point displacement from the marker is known in advance.

B. Case 2

This landing region consists of a man-made marker on the lunar surface, some areas unsuitable for landing and distinguishable natural features which can be used to direct the LEM towards the marker. Again orbiter photographs are used in the pre-mission classification of this landing region. Alternate landing points are selected with respect to both the distinguishable natural features and the man-made marker in the event the marker is not acquired or if the marker cannot be reached. Landing to this type of region influences the descent strategy in the following manner.

Higate can be selected at a "reasonable" natural feature acquisition distance. The term "reasonable" distance is used to indicate a tradeoff study between the effectiveness of using the natural features to aid in the acquisition of the marker versus the ΔV penalty associated with the higate maneuver and the duration of the visibility phase. Biasing of the estimated marker position may not be necessary in this case due to the availability of usable natural features well in advance of the marker acquisition distance. Since there are some areas unsuitable for landing, the time allotted for marker acquisition must be limited. The acquisition interval will vary depending on the particular size and distribution of these unsuitable areas and their displacements from the nominal and alternate landing points. If the marker is acquired, the crew must determine whether or not the marker is within the ΔV and loss of line-of-sight constraints. The allowable

interval of loss of line-of-sight to the marker will vary depending on the proximity of the unsuitable areas to the nominal landing point and the accuracy with which the corrective maneuver can be accomplished.

If the marker is not acquired the crew can use the natural features to select a preplanned alternate landing point while, if the marker is acquired but cannot be reached, the marker can be used by the crew to select a preplanned alternate point. As in Case 1, an azimuth turn may be used to improve surface relief during the landing phase.

C. Case 3

This landing region differs from the Case 2 landing region in that there are no usable natural features to aid the crew in acquiring the marker. As a result, preplanned alternate landing points can be selected only with respect to the marker. However, the size and distribution of unsuitable landing areas is known in advance from the analysis of lunar orbiter photographs. Landing to this type of region effects the descent strategy in the following manner.

Higate can be selected slightly in advance of the marker acquisition distance to afford the crew sufficient time to determine whether or not there are obstacles to be avoided before initiating a search for the marker. As in Case 1, the estimated marker position may be biased uprange. The intervals allowed for marker acquisition and the number and magnitude of the downrange corrections, however, may be limited by the size and distribution of the particular unsuitable landing areas. As shown in Figure 1, the remainder of this sequence is similar to Cases 1 and 2.

D. Case 4

This landing region differs from the previous cases in that there are no lunar orbiter photographs of the landing site. No attempt is made to justify the selection of this type of landing region other than to say that sufficient information exists which allows it to be classified as an acceptable site, containing a sufficient number of suitable landing points. It is further assumed here that the site contains some areas to be avoided and no usable natural features. The difference between this Case and Case 3 is then in the degree of detailed information, and hence confidence in the landing region, prior to the actual mission. Landing to this type of region influences the descent strategy in the following way.

Higate, as in Case 3, can be selected in advance of the marker acquisition distance to assure the LEM approach path is free from obstacles. Again, the estimated marker position may be biased uprange with sufficient time allocated,

after the corrective process, for alternate landing point selection. If the marker is acquired and the maneuver is within the ΔV and loss of line-of-sight constraints, the crew must determine whether or not the marker point appears acceptable. A slightly longer duration for landing point evaluation and azimuth turn, to improve visibility of surface relief, may be required for this type of landing region than those cases previously considered.

IV. Landing to a Site Not Containing a Man-made Marker

Figure 2 illustrates the four cases which are possible when no man-made marker is contained within the chosen landing site. The classification of these sites, with the exception of the marker, are more or less identical to those considered previously, however, they do influence the descent strategy differently. The differences are noted in Figure 2 and discussed in detail below.

A. Case 5

This landing region is classified as all good from an analysis of lunar orbiter photographs. As in Case 1, there are areas to be avoided in the landing phase and there are no usable natural features. Landing to this type of region influences the descent strategy in the following manner.

Higate can be selected at a shorter distance and lower altitude than is possible when landing to any other type of region. As mentioned before, there is a ΔV penalty associated with the visibility phase, hence this represents the minimum penalty case. There is also a ΔV penalty associated with reducing thrust to a throttleable level in Phase I in order to correct for the expected descent propulsion system dispersions. If the size of this good site were comparable to the distance traversed when this dispersion is not corrected or only partially corrected, an additional savings in terms of LEM weight reduction or increased hover time could be realized. After higate, the crew evaluates the present landing point and determines if an azimuth turn is required to improve surface relief.

B. Case 6

This landing region is classified, from lunar orbiter photographs, as one containing usable natural features in addition to some areas unsuitable for landing. Landing to this type of region influences the descent strategy in the following way.

Higate can be based on the distance and altitude at which the natural features can be effectively used to direct the LEM away from unsuitable areas and towards an acceptable landing point. Possible ΔV savings can be gained, in this case as opposed to the following two, in that, through the use of natural features more efficient corrections can be made. After selecting the landing area, the crew decides whether or not the visibility of surface relief is sufficient for continuous landing point evaluation in the landing phase.

C. Cases 7 and 8

The basic difference in these two cases is the means by which the landing site is classified. Case 7 assumes the site to be classified from lunar orbiter photographs, while Case 8 assumes the site is classified using "present knowledge" of the lunar surface. Both have areas to be avoided and do not have usable natural features. Landing to these types of regions influence the descent strategy as follows.

Higate, for both cases, can be selected based on the requirement to reach a good point. By that we mean that knowing the size and distribution of the unacceptable landing areas, higate is selected at a distance and altitude which allows the crew sufficient time to maneuver the LEM away from these areas and to an acceptable point. Of course, in Case 7, more detailed information is available than in Case 8. This in effect means that if Case 8 is used, a more conservative estimate of the position of higate will be used, and more time in the landing phase may be required than in Case 7, resulting in a ΔV penalty for Case 8. As shown in Figure 2, the remainder of the strategy is identical for both cases.

V. Summary

When landing to a region in which the nominal landing point is near a man-made marker, the probability of acquiring the marker and attaining the nominal landing point is highly dependent on the marker acquisition distance. Since the allowable ΔV for corrective maneuvers is limited and the attainable area diminishes as the LEM nears the lunar surface, timely acquisition is essential if the nominal point is to be achieved. Although biasing the estimated marker position up-range and performing downrange corrections, if the marker is not acquired with a given interval, increases the probability of acquiring the marker a ΔV penalty is always incurred with this scheme. The availability of distinguishable natural features, usable well in advance of the marker acquisition distance, improves the probability of attaining the marker

in that more efficient corrections can be implemented than is possible in the other cases. In general, if the objective is to land near a marker rather than to any other acceptable point in the landing site, the cost, in terms of ΔV, is higher. Landing to a region not classified by lunar orbiter photographs will generally involve a ΔV penalty due to the lack of detailed knowledge concerning the size and distribution of unsuitable landing areas.

R. E. Driscoll

2023-RED-nrd

Attachments:
Figure 1
Figure 2

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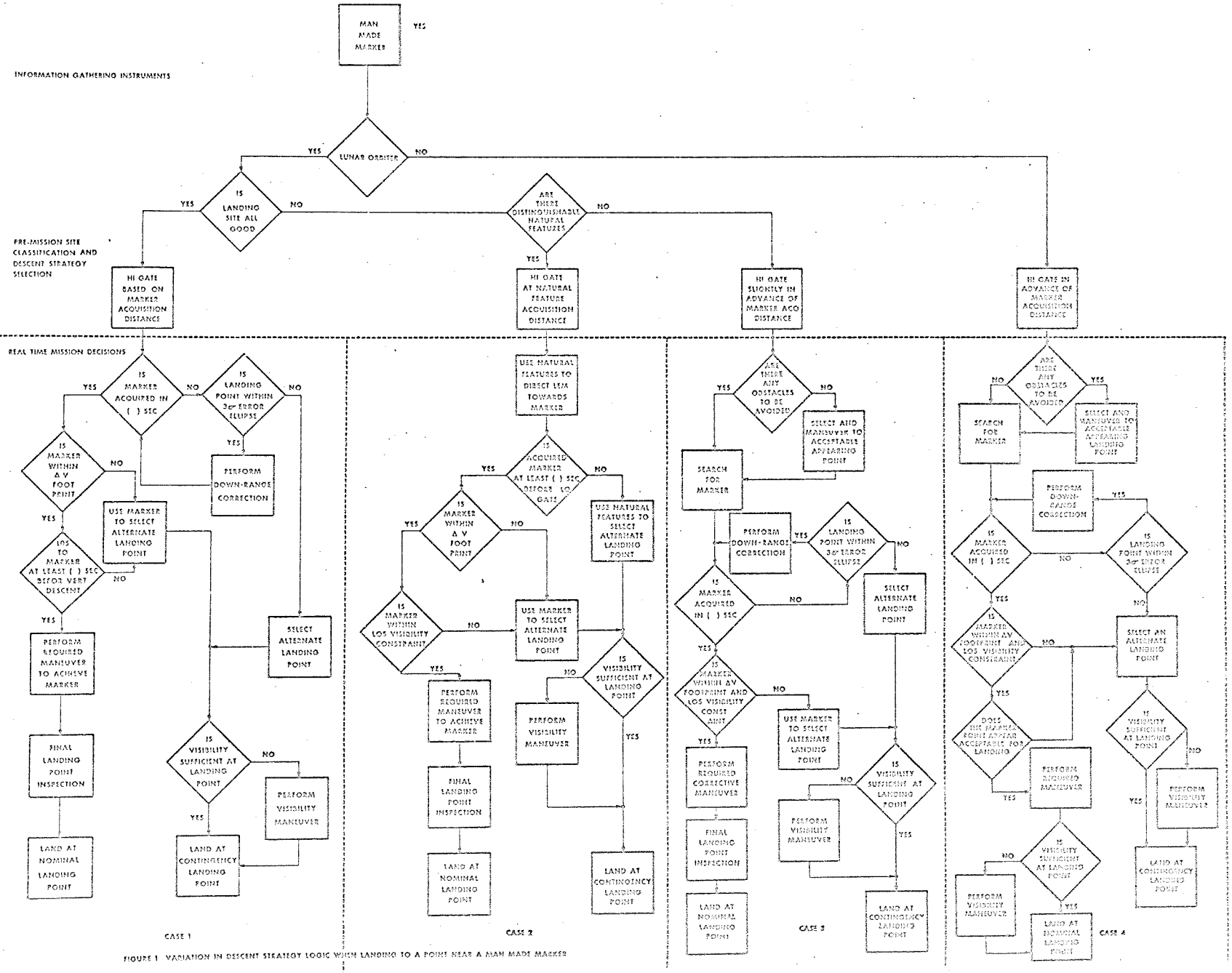
INFORMATION GATHERING INSTRUMENTS
MAN MADE MARKER
YES
LUNAR ORBITER
YES
NO
PRE-MISSION SITE CLASSIFICATION AND DESCENT STRATEGY SELECTION
IS LANDING SITE ALL GOOD
YES
NO
ARE THERE DISTINGUISHABLE NATURAL FEATURES
NO
YES
HI GATE BASED ON MARKER ACQUISITION DISTANCE
HI GATE AT NATURAL FEATURE ACQUISITION DISTANCE
HI GATE SLIGHTLY IN ADVANCE OF MARKER ACQ DISTANCE
HI GATE SN ADVANCE OF MARKER ACQUISITION DISTANCE
REAL TIME MISSION DECISIONS
IS MARKER ACQUIRED IN ( ) SEC
IS LANDING POINT WITHIN 3σ ERROR ELLIPSE
IS MARKER WITHIN ΔV FOOT PRINT
PERFORM DOWN-RANGE CORRECTION
USE MARKER TO SELECT ALTERNATE LANDING POINT
LOS TO MARKER AT LEAST ( ) SEC BEFOR VERT DESCENT
SELECT ALTERNATE LANDING POINT
PERFORM REQUIRED MANEUVER TO ACHIEVE MARKER
FINAL LANDING POINT INSPECTION
LAND AT NOMINAL LANDING POINT
IS VISIBILITY SUFFICIENT AT LANDING POINT
PERFORM VISIBILITY MANEUVER
LAND AT CONTINGENCY LANDING POINT
CASE 1
USE NATURAL FEATURES TO DIRECT LEM TOWARDS MARKER
IS ACQUIRED MARKER AT LEAST ( ) SEC BEFORE LO GATE
IS MARKER WITHIN ΔV FOOT PRINT
USE NATURAL FEATURES TO SELECT ALTERNATE LANDING POINT
IS MARKER WITHIN LOS VISIBILITY CONSTRAINT
USE MARKER TO SELECT ALTERNATE LANDING POINT
PERFORM REQUIRED MANEUVER TO ACHIEVE MARKER
IS VISIBILITY SUFFICIENT AT LANDING POINT
PERFORM VISIBILITY MANEUVER
FINAL LANDING POINT INSPECTION
LAND AT NOMINAL LANDING POINT
LAND AT CONTINGENCY LANDING POINT
CASE 2
ARE THERE ANY OBSTACLES TO BE AVOIDED
SELECT AND MANEUVER TO ACCEPTABLE APPEARING POINT
SEARCH FOR MARKER
PERFORM DOWN-RANGE CORRECTION
IS LANDING POINT WITHIN 3σ ERROR ELLIPSE
IS MARKER ACQUIRED IN ( ) SEC
SELECT ALTERNATE LANDING POINT
IS MARKER WITHIN ΔV FOOTPRINT AND LOS VISIBILITY CONSTAINT
USE MARKER TO SELECT ALTERNATE LANDING POINT
PERFORM REQUIRED CORRECTIVE MANEUVER
IS VISIBILITY SUFFICIENT AT LANDING POINT
FINAL LANDING POINT INSPECTION
PERFORM VISIBILITY MANEUVER
LAND AT NOMINAL LANDING POINT
LAND AT CONTINGENCY LANDING POINT
CASE 3
ARE THERE ANY OBSTACLES TO BE AVOIDED
SEARCH FOR MARKER
SELECT AND MANEUVER TO ACCEPTABLE APPEARING LANDING POINT
PERFORM DOWN-RANGE CORRECTION
IS MARKER ACQUIRED IN ( ) SEC
IS LANDING POINT WITHIN 3σ ERROR ELLIPSE
IS MARKER WITHIN ΔV FOOTPRINT AND LOS VISIBILITY CONSTRAINT
SELECT AN ALTERNATE LANDING POINT
DOES THE MARKER POINT APPEAR ACCEPTABLE FOR LANDING
PERFORM REQUIRED MANEUVER
IS VISIBILITY SUFFICIENT AT LANDING POINT
PERFORM VISIBILITY MANEUVER
IS VISIBILITY SUFFICIENT AT LANDING POINT
PERFORM VISIBILITY MANEUVER
LAND AT NOMINAL LANDING POINT
LAND AT CONTINGENCY LANDING POINT
CASE 4

FIGURE 1 VARIATION IN DESCENT STRATEGY LOGIC WITH LANDING TO A POINT NEAR A MAN MADE MARKER

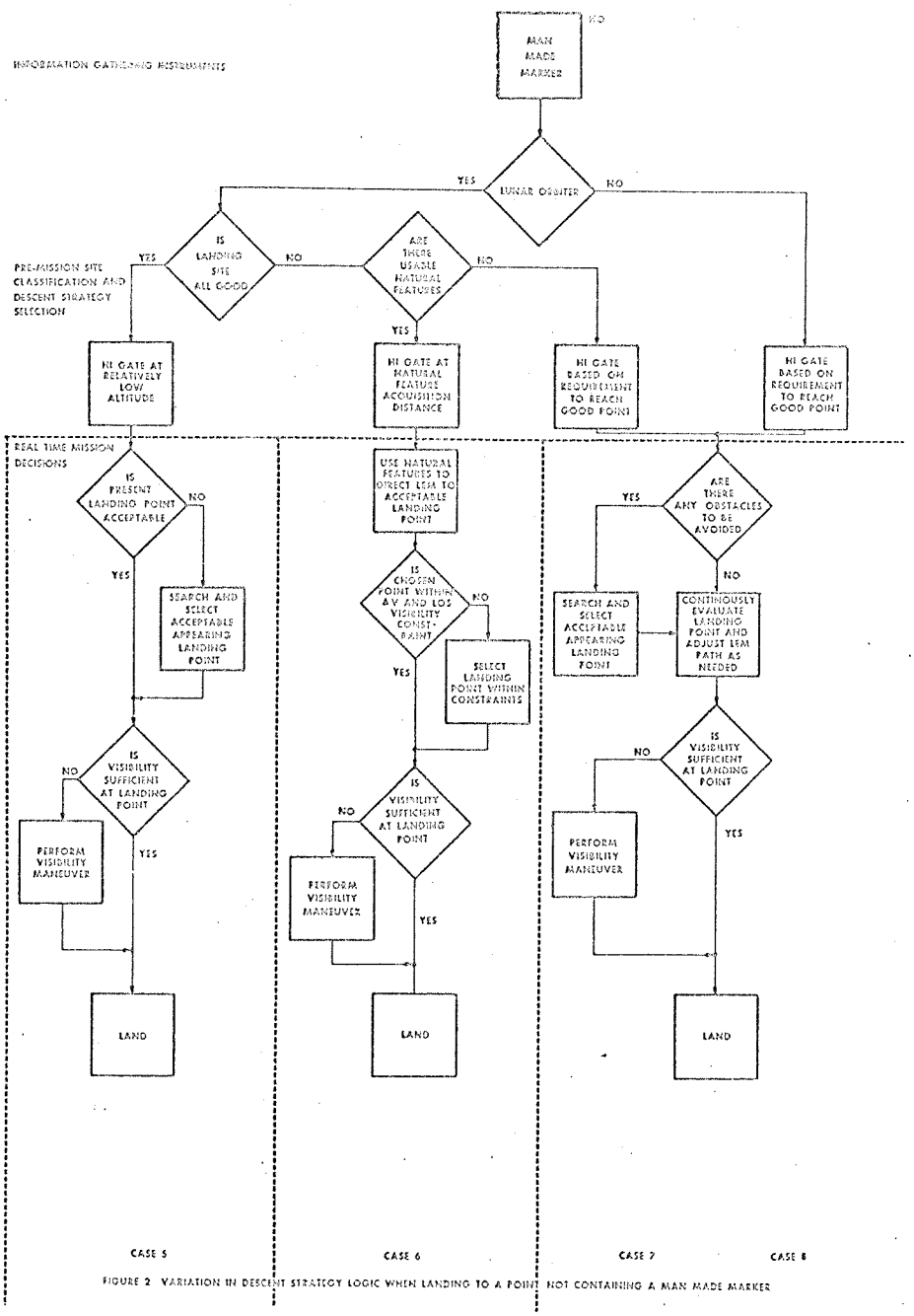

FIGURE 2 VARIATION IN DESCENT STRATEGY LOGIC WHEN LANDING TO A POINT NOT CONTAINING A MAN MADE MARKER